PARAMETERIZATION OF AN ANISOTHERMAL VEGETATION CANOPY

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PROJECT SUMMARY

This one-year project will *test and validate an analytical sensible heat flux parameterization of an anisothermal vegetation canopy and develop techniques which will extend its usefulness*. Sensible heat flux estimates employing radiometric surface temperatures in surface layer and bulk atmospheric boundary layer similarity theory, as well as in convective turbulence theory, require local calibration, or an estimate of the ambiguous aerodynamic surface temperature. As neither of these options is appealing in the context of widespread surface flux estimates with remotely sensed surface temperatures, an alternative parameterization has been developed, which must now be validated with field data.

Based on work by Brutsaert and Sugita (1996), the soil surface temperature and a vertical foliage temperature profile have been incorporated in a turbulent transfer and canopy-radiometer parameterization. In this parameterization, analytical expressions have been developed to: 1) convert the radiometric temperature of an anisothermal canopy to the equivalent isothermal surface temperature, akin to an aerodynamic surface temperature; and 2) estimate the scalar roughness length for sensible heat (z_{0h}) for an anisothermal canopy for any radiometer view angle. Data from FIFE [the First International Satellite-Land Surface Climatology Project (ISLSCP) Field Experiment] and from a pasture in Japan will be used to validate the model in preparation for widespread use with remotely sensed data for testing and calibration of predictive models and monitoring of energy fluxes from changing land surfaces.

PROJECT PLAN

Introduction

Surface sublayer or Monin-Obukhov similarity theory (MOST), atmospheric boundary layer similarity theory (ABLST) [e.g., Brutsaert, 1982], and Convective Transport Theory (CTT) [Stull, 1994] can all be used with radiometric surface temperatures measured with an infrared thermometer (IRT) to estimate H, the surface sensible heat flux into the atmosphere. However, each of these theories has failed to the extent that similarity parameters have been locally calibrated, or ambiguous definitions of surface temperature have been used.

To address this problem, an analytical parameterization of the anisothermal canopy has been developed, which links both turbulent heat transfer and radiometric surface temperature with the vertical temperature profile of the foliage [$q_f(z)$]. It provides the scalar roughness length (z_{0h}) appropriate for the radiometric surface temperature measured at any view angle ($q_{s,r}$), and can transform this temperature to the equivalent isothermal surface temperature which the atmosphere feels ($q_{s,i}$).

Objective

The long-term objective is to use this parameterization, with remotely-sensed radiometric surface temperatures, to derive unambiguous surface temperatures and unbiased surface sensible heat fluxes on a wide-spread basis for testing and calibration of predictive models and monitoring of energy fluxes from changing land surfaces. Towards this end, *the objective of this one-year proposal is to validate the model through analysis of field data, and to develop techniques which will extend its usefulness.*

Theory

This project is based on work by Brutsaert and Sugita (1996; hereafter referred to as B&S). They started with an expression for the foliage temperature profile:

$$q_f = q_{fg} + (q_{fh} - q_{fg})\, e^{-bV} \tag{1}$$

where q_f is the foliage temperature at height z, $V=(h-z)/h$ is the dimensionless depth into the canopy, h is the canopy height, q_{fg} and q_{fh} are the values of q_f at the bottom and top of the canopy, respectively, and b is the profile shape parameter. The profile described by (1) is shown in Figure 1. B&S described the radiometric surface temperature with:

$$q_{s,r} = w\, q_{fh} + (1 - w)\, q_{fg} \tag{2}$$

which defines w, the weighting fraction. Using a K-theory approach, B&S derived a differential equation which describes vertical turbulent transfer of sensible heat through a canopy with a temperature profile described by (1). By solving this equation and using the MOST formulation for H, they were able to derive an expression for $z_{0h,r}$ for any given value of w. They also derived an equivalent isothermal scalar roughness, $z_{0h,i}$, which is a property only of canopy parameters and turbulence. The equivalent isothermal surface temperature, $q_{s,i}$, is the temperature which gives the correct value of H when z_{0h} is given the isothermal value, $z_{0h,i}$, in the MOST sensible heat flux formulation.

Crago [1998] extended this work by deriving an expression for w for a radiometer which views the surface from any view zenith angle. This led to expressions for $z_{0h,r}$ which should give unbiased estimates of H when used with $q_{s,r}$ measured with a radiometer having any given zenith view angle. The key to using these expressions is the determination of b, q_{fg} and q_{fh}.

Research to be Conducted

To experimentally validate the parameterization and prove its usefulness, it must be shown that the equations coherently explain field measurements of IRT temperatures and sensible heat fluxes. This will be done using data from FIFE and from an experiment in a pasture in Japan [Kubota and Sugita, 1994].

Task A: Stand-Alone Canopy-IRT Tests

Multi-angle IRT data from FIFE [Vining and Blad, 1992] and from the pasture in Japan [Kubota and Sugita, 1994] will be used to estimate the   optimal   values of q_{fh}, q_{fg} and *b*. The optimal value will be the one which reduces the rms difference between measured and parameterized IRT temperatures at the different view angles. The idea is to show that q_{fh}, q_{fg} and *b* can be found such that the parameterization adequately describes the observed variability of IRT temperatures at different view angles. Preliminary tests by Crago [1998] indicate that a single optimal combination of variables may not always be available from the IRT data alone. Three methods to constrain the optimization better will be explored.

First, q_{fh} can be set equal to the site-wide air temperature, q_a, at a height of approximately two meters, while optimal values of q_{fg} and *b* are found [c.f. Friedl and Davis, 1994]. Second, a force-restore model can be used to find the soil surface temperature, which will be set equal to q_{fg}. In this case, the values of q_{fh} and *b* will be optimized. Third, a fixed value of *b* can be assumed, and optimal values of q_{fh} and q_{fg} can be found.

Task B: Combined canopy-IRT and turbulent transfer parameterization

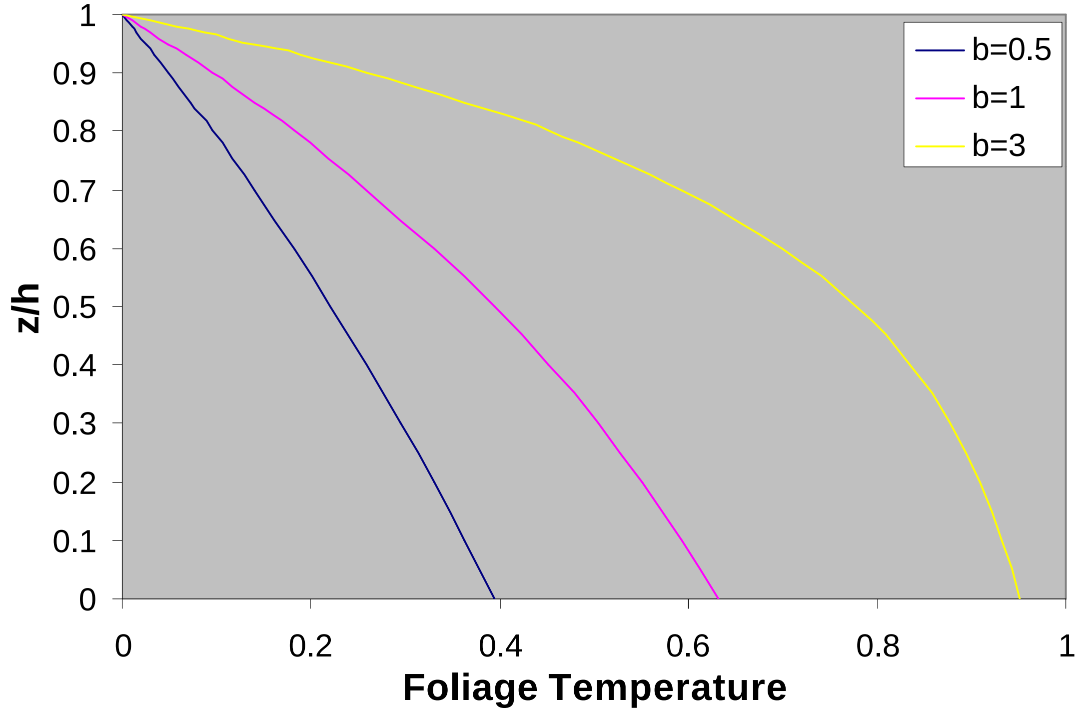
Task B will test the values of q_{fg}, q_{fh} and *b* (already obtained from Task A) within the turbulent transfer portion of the model. Sensible heat fluxes, air temperatures, u_* values, and surface temperatures are available at a variety of scales at FIFE, and at local scales for the pasture data. Using known values of q_{fg}, q_{fh} and *b*, the turbulent transfer parameterization will be tested in several different modes. Predicted sensible heat fluxes will be compared to measured fluxes, and parameterized isothermal surface temperatures will be compared to values obtained through Monin-Obukhov similarity theory using measured fluxes and air temperatures. Comparisons will be made across the range of scales available. Assessment of the parameterization at each scale will be based on its ability to explain coherently the flux, surface temperature, and meteorological field data.

Expected Results

The proposed work has the potential to lead to more accurate and routine surface sensible heat flux estimates and to solid physically-based estimates of the effective or aerodynamic surface temperature (i.e., $q_{s,i}$).   It constitutes a critical step toward widespread collection of surface energy and water vapor fluxes at scales appropriate for calibrating, testing, and driving predictive models.

The proposed work will primarily confirm that the parameterization coherently explains both IRT and turbulent sensible heat flux data. In addition, some of the techniques used in this validation to estimate the unknown parameters are expected to be transferable to the case of widespread use with remotely sensed data. Finally, should methods be developed to parameterize q_{fg}, q_{fh}, and *b* as functions of solar angle, cloudiness and other external variables, the turbulent transfer portion could be included in numerical simulation models of the atmosphere. This research will provide significant field support for such work.

Fig. 1 Foliage Temperature Profile, for case in which canopy top temperature is 0, canopy bottom temperature is 1



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